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Effect of Flea Beetles (*Aphthona Nigriscutis*) on Prairie Invaded by Leafy Spurge (*Euphorbia Esula*) in Maintoba

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EFFECT OF FLEA BEETLES (*APHTHONA NIGRISCUTIS*) ON PRAIRIE INVADED BY LEAFY SPURGE (*EUPHORBIA ESULA*) IN MANITOBA

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ABSTRACT—Leafy spurge (*Euphorbia esula*) is an invasive exotic weed in Great Plains rangelands and pastures. *Aphthona nigriscutis*, the black dot flea beetle, was released as a biological control agent in nine heavily infested sites in south-central Manitoba (three sites in 1986, three in 1988, and three in 1990). In 1992 we evaluated beetle impact by sampling the vegetation in 25 x 25 cm quadrats. We measured cover, height, density, and biomass of leafy spurge, the cover of litter and bare ground, and the presence of other plant species both at the release point and at randomly-chosen nearby nonrelease reference points at each site. Leafy spurge near the release points showed significantly lower cover, biomass, height, and stem density than at the reference points. Also, release points had significantly more bare ground, higher grass and sedge biomass, and greater plant diversity. Other plant species, especially perennial grasses and sedges, increased in frequency, while frequency of leafy spurge did not change over time. Data such as these are important if we are to employ management techniques that can both reduce invasive weeds and restore native species diversity to the Great Plains prairies and rangelands.

KEY WORDS: leafy spurge (*Euphorbia esula*), black dot flea beetle (*Aphthona nigriscutis),* mixed-grass prairie, native vegetation, recovery

Introduction

Leafy spurge (*Euphorbia esula* L.) is a widespread native of Europe and temperate Asia that tolerates a broad range of climate and substrate. It is a deeply rooted perennial, 30 to 100 cm tall, that was first collected in Massachusetts in 1827 (Selleck et al. 1962). It is now believed to infest 2 million hectares across all the provinces in Canada except Newfoundland and in 35 states in the United States (Anderson et al. 2000). By 1978 it was declared a serious economic weed, particularly in the Great Plains. Where it occurs it can reduce both productivity and native species diversity (Masters et al. 1996). For example, Lym (1998) reported that leafy spurge reduced forage production by as much as 75%. Losses from leafy spurge have been estimated to exceed $92 million annually (Thompson et al. 1990). The number of hectares infested in southern Manitoba increased from 3,000 ha in 1952 to 54,600 ha in 1995 (Lethbridge Research Centre 1999). According to the Manitoba Leafy Spurge Stakeholders Group (1999), leafy spurge infests an estimated 90,000 ha (225,000 acres) of pastureland, having an economic impact of $16 million per year. Its economic impact on public lands and rights-of-way amounts to almost $3 million annually and land values are potentially reduced by $30 million (Leafy Spurge Stakeholders Group 1999).

The early and rapid growth and vegetative spread of leafy spurge gives it a competitive advantage over native range plants (Lym 1998). It is a persistent species that can strongly influence plant community structure by its numbers, size, and spacing (Loucks et al. 1985). Successful control of leafy spurge requires killing the roots and associated vegetative buds (Lym 1998). Since tillage can control leafy spurge in cropland, it has generally been considered a rangeland problem. Bangsund et al. (1993), however, brought attention to infestations of "wildland," other untilled lands not used for agriculture, for example, parks, wildlife management areas, river banks, and roadsides. In such situations, when dense enough, leafy spurge can reduce a whole range of conservation benefits.

Belcher and Wilson (1989) looked at the relationship between leafy spurge and the species composition of mixed-grass prairie on a large scale (200 km^2) and on a small scale (<1 ha) in southwestern Manitoba. At both scales, they found that in the presence of leafy spurge, the cover of native species was significantly lower, and the cover of nonnative Eurasian species significantly higher. They indicated that infestations were mainly associated with anthropogenic disturbances.

Herbicides can effectively control leafy spurge, and they have been recommended in combination with other control methods, such as sheep or goat grazing and seeding of competitive grass species (Masters et al. 1996; Lym 1998). For example, 2,4-D plus picloram kills most of the root system of leafy spurge and achieves effective control when applied annually for three to five years (Lym 1998). However, picloram breaks down slowly and has not been recommended for use in natural areas (Cole 1991). Both dicamba and glyphosate have proved useful (Messersmith and Lym 1990). Also, several imidazolinone-type herbicides have been shown to be important components of an integrated weed management program to restore grasslands in the Great Plains, since several key native grasses and forbs can tolerate them (Masters et al. 1996). In mixed-grass prairie or rangeland on sandy soils (Lym 1998), such as occur in southwestern Manitoba, eastern Saskatchewan, and North Dakota, herbicides like picloram must be used with caution because of potential percolation into the groundwater table. Picloram and other herbicides (e.g., glyphosate and 2,4-D) can be used if the water table is sufficiently deep. Often, however, effectiveness requires that herbicide residues in soils are maintained for a number of years and, thus, herbicides may not be ecologically desirable or economically feasible (Bangsund et al. 1993; Lym 1998). These considerations, along with the inaccessibility of many leafy spurge-infested sites, may prevent herbicides from being a viable solution (Kirby et al. 2000).

Biological control of leafy spurge has been used as an alternative to chemicals. It has met with some success, particularly in combination with other methods (e.g., grazing) as part of an integrated control program (Lym 1998). Classical biological weed control—the introduction of exotic natural enemies from the area of origin of the weed (Harris et al. 1985)—is a slow process. It generally requires several years before the population of the control organism reaches numbers able to achieve a lower density of the weed. The target organism is not eradicated in successful programs, but often it may be controlled at about 10% cover (Harris et al. 1985).

Fifteen insect species have been released for biological control of leafy spurge since 1964, including six species of flea beetle, *Aphthona* (Anderson et al. 2000). The black dot flea beetle (*Aphthona nigriscutis* Foudras [Chrysomelidae]) was introduced from Hungary after it had been tested rigorously for its specificity to leafy spurge. It was then released in a number of leafy spurge-infested sites on the Canadian prairies. It is cold-hardy and can reach densities high enough to impact the weed (Harris et al. 1985). Since 1983 more than 1,200 black dot and 350 brown dot (*Aphthona* *cyparissiae* Koch.) flea beetle release sites have been established in Manitoba (Manitoba Agriculture 1997). Unfortunately, no data are available on the fate of many of these beetle populations. The black dot flea beetle prefers plants on sandy soils in sunny locations, while the brown dot flea beetle prefers more moist loamy sites and can tolerate denser vegetation (Manitoba Agriculture 1997). The adults defoliate the aerial parts of the leafy spurge plants while the larvae feed on the root systems (Harris et al. 1985).

At some of the earliest beetle release sites in Manitoba, leafy spurge density has decreased by 95% (Manitoba Agriculture 1997). Although Lym (1998) cited problems in *Aphthona* spp. establishment at some sites in North Dakota, Kirby et al. (2000) also reported that aboveground cover, density, and yield of leafy spurge was reduced at release sites in east-central North Dakota. Two years after release, other species such as grasses, were colonizing the center of the release sites. Similar results were reported in a 1989 release site in the northern United States (Wendel and Hansen 1992).

The genus *Euphorbia* is segregated into two major groups, although only one group, *Esula*, is host to *Aphthona nigriscutis*. The other group, *Chamaesyce*, is not eaten by *A. nigriscutis*. The two native species of spurge that occur in southern Manitoba, ridge seed spurge (*Euphorbia glyptosperma* Englm.) and thyme-leaved spurge (*E. serpyllifolia* Pers) both belong to the *Chamaesyce* group and are not affected by *Aphthona* spp. (Harris et al. 1985, Animal and Plant Health Inspection Service 1994).

In this study we examined plant community response where *Aphthona nigriscutis* had been released to suppress leafy spurge. By sampling a number of release and nonrelease (reference) points associated with sites that differed in release years, we measured the beetle's impact on leafy spurge and quantified plant community differences at two, four, and six years after beetle release in Manitoba prairie.

Methods

Study Location

The study took place on the Assiniboine Delta in south-central Manitoba within the rural municipalities of Victoria and North and South Norfolk. The area lies in the aspen-oak section of the Boreal Forest Region (Rowe 1972) and the Canadian Aspen Forest and Parkland (Ecological Stratification Working Group 1995). The parkland is a broad transition zone between the boreal forest and the prairie. All our sites were mixed-grass prairie, with occasional aspen (*Populus tremuloides* Michx.), bur oak (*Quercus macrocarpa* Michx.), and white spruce (*Picea glauca* [Moench] Voss) (see Scoggan 1978-1979). The Assiniboine Delta is divided into two broad physiographic areas by the Manitoba Escarpment (Ehrlich et al. 1957). The Upper Assiniboine Delta lies above 335 m and is west of the escarpment, while the Lower Assiniboine Delta is to the east between 274 m and 305 m.

Manitoba Agriculture released black dot flea beetles (*Aphthona nigriscutis*) in five locations in the Assiniboine Delta in 1986, four in 1988 and four in 1990 (Mico 1993). The leafy spurge infestations ranged in size from 1 to 20 ha. In 1992 we selected nine locations, three to represent each release year. Soils in locations where beetles had been released were coarse-textured outwash and lacustrine deposits modified by eolian action. Six sites (1, 2, 3, 4, 7, and 9 in Table 1) were located on the Upper Assiniboine Delta and three sites (5, 6, and 8 in Table 1) in the Lower Delta. To minimize site differences, we selected release locations that had similar soil properties, slope, and aspect (Table 1). All the release points were within an extensively infested spurge area within which we randomly selected a comparative reference point.

Plant Survey

We sampled Sites 1 to 6 between 6 and 9 August 1992, and Sites 7 to 9 between 1 and 10 September 1992. In each site the beetle release point had been marked with a wooden stake at the time of beetle release. In 1992 all release points had a noticeable area, roughly circular, and approximately 10 m in diameter (range 8-10 m), without much leafy spurge.

Two 10-m-long transects were set up within the area adjacent to the stake, with the stake as the center. One transect was oriented north-south, the other east-west. Quadrats were placed every meter along both transects, resulting in 20 quadrats per site. Our choice of quadrat size to sample the vegetation was governed by several considerations. Leafy spurge stems (ramets) tend to be evenly distributed, and preliminary sampling using quadrats of various sizes did not significantly change the estimate of leafy spurge frequency. We found the 25 x 25 cm quadrat was a convenient size for identifying every plant in the quadrat (Anderson and Bailey 1980; Goldsmith et al. 1986). Also, Goldsmith et al. (1986) found that 10 x 10 cm or 25 x 25 cm quadrats were appropriate for the study of grassland, arable weeds, and dune grassland. For each 25 x 25 cm quadrat, we estimated cover

TABLE 1

LOCATION CHARACTERISTICS OF THE NINE BEETLE RELEASE SITES

Beetle release			Soil		Slope		Land use	
Site	Date	No.	Series	Drainage	(%)	Aspect	Present	Adjacent
1	1986	nd	Shilox	Well to excessive	2	East	Private pasture	Private pasture
2	17/7/86	500	Shilox	Well to excessive	5	South	Provincial park	Provincial park
8	86/7/23	60	Almasippi	Impaired	6	South	Wildlife corridor	Private pasture
3	1988	nd	Shilox	Well to excessive	6	South	Private pasture	Community pasture
6	1988	nd	Skelding	Excessive	11	East	Wildlife corridor	Private pasture
7	11/7/88	200	Dobbin-Shilox	Excessive	17	East	Private pasture	Private pasture
4	23/7/90	500	Shilox	Well to excessive	4	South-east	Wildlife corridor	Agriculture field
5	23/7/90	500	Skelding	Excessive	0	Flat	Wildlife corridor	Agriculture field
9	23/7/90	500	Dobbin-Shilox	Well to excessive	2	East	Wildlife corridor	Agriculture field

Sources: Beetle release data: Manitoba Agriculture (unpublished manuscript); Soil data: Langman (1988, 1989) and Podolsky (1991)
Note: nd = no data

of spurge, bare ground, and litter to the nearest 10%, counted the number of leafy spurge stems, and measured the height of each stem. All other species present within the quadrat were recorded.

We selected three quadrats (25 x 25 cm) at random from the two transects, clipped all the aboveground biomass (Dhillion et al. 1988; Wilson and Shay 1990), and collected the litter. These samples were later separated into leafy spurge, graminoids (grasses and sedges), forbs (broad leafed plants), and litter. Each portion was dried at 90°C to a constant mass and weighed.

Reference points were selected randomly, using a compass-bearing from the marker stake at each release point and a randomly chosen distance (15-60 m) from the stake. This point became the center of the two reference transects of quadrats. No beetles were observed at these reference points. The quadrats for the reference points were sampled in the same manner as the release points.

Soil Collection and Analysis

At each site, slope and aspect were recorded and a soil pit was opened to facilitate sampling and description of the soil profile. The A horizon was sampled from each soil (within the upper 5 cm) and a core was taken to determine the depth of the C horizon and to obtain a soil sample. The C horizon in Site 5 could not be sampled due to the high water table. Soil samples were placed in airtight plastic bags and stored at 4°C in the laboratory until analyzed.

Fresh soil samples were hand-textured into classes according to the Canadian System of Soil Classification (Agriculture Canada 1987). Dry color (hue, value, and chroma) was assigned to each subsample using Munsell color charts (1975). Approximately 60 g was removed from each sample and weighed, dried at 105°C for approximately 16 hours, and then reweighed to determine percentage of soil moisture. Conductivity and pH were determined using the dilution extract method (Page et al. 1982). Organic matter content of each soil sample was determined by ashing and calculated as a percentage.

Data Analysis

For each nonrelease and release point at each site, we calculated the mean for the 20 quadrats for each variable (cover and frequency of spurge, bare ground and litter, spurge density and height, and the number of species per quadrat). We also tallied the total number of species per sampling point and determined biomass of spurge, graminoids, forbs, and litter as the average for the three clipped quadrats at the beetle-release points and in the three quadrats at the reference point. The data from each beetle release point were compared with its reference point. Both litter and forbs contributed less than 1% to the total biomass and were not used in further analysis.

We tested heterogeneity of error variances and normality within each site and across sites. The data were neither normally distributed nor had equal variances (K-S Lillifores and Levene's Test, respectively, SPSS 1994). Thus, we used nonparametric statistics to evaluate differences. To determine if leafy spurge, bare ground, litter, and abundance of other species differed between each release and reference point pair, we used a Wilcoxon paired-sample test (Sokal and Rohlf 1980). The variables that differed significantly at the beetle release point were then used to determine if there was a significant change in these variables over time (1986-88 and 1986-90), using the Kruskal-Wallis test (Sokal and Rohlf 1980). Our null hypothesis was that *Aphthona nigriscutis* had no effect on leafy spurge performance and density.

Results

Location Characteristics

The six sites on the Upper Assiniboine Delta (1, 2, 3, 4, 5, 7, and 9) occur on soils from the Stockton Association developed on deep, sandy deltaic deposits (Ehrlich et al. 1957). All beetle release and reference points at these sites were characterized by dune topography, with slopes ranging from 2% to 17% and an east or south aspect (Table 1). Recent detailed soil surveys classified the soils as the Shilox Series (Langman 1989; Podolsky 1991). The Shilox Series consists of well- to excessively drained Orthic Regosol soils developed on weakly to noncalcareous, deep, uniform sandy eolian deposits. They have slight organic matter accumulation in the upper 5 to 10 cm (Table 2).

The three sites sampled from the Lower Assiniboine Delta (sites 5, 6, and 8) occur on soils from the Almasippi Association developed on shallow sandy deposits (Ehrlich et al. 1957). Topography at these sites ranges from flat to hummocky, with slopes of 6% and 11% and east or south aspects (Table 1). Detailed soil surveys of this area indicated that two sites were classified in the Skelding Series while one was in the Almasippi Series (Langman 1988; Podolsky 1991). Skelding and Shilox soils are very similar (G. Mills personal communication).

There were no significant differences in any of the soil parameters between release (Table 2) and reference points at any site. In summary, all the sites can be considered to have similar soils (G. Mills personal communication).

Land use and number of black dot flea beetles released varied between sites (Table 1). Some sites were pastures or were within 1 km of agricultural fields, so in past years their flora could have been influenced by grazing,

TABLE 2

SOIL CHARACTERISTICS FROM LEAFY SPURGE SITES (SEPTEMBER 1992)

Site (year)[a]	Horizon	Depth (cm)	Color (dry)[b]	Texture	Moisture (%)	pH	Conductivity (μS)	Organic matter (%)
1	A	2	10YR 3/1	sand	8.3	6.9	79	3.0
	C	40	10YR 4/3	sand	7.6	6.6	45	0.5
2	A	2	10YR 4/1	sand	8.1	6.7	70	2.5
	C	40	10YR 5/4	sand	3.6	6.8	42	0.5
9	A	3	10YR 3/1	sand	10.6	7.2	93	3.2
	C	90	10YR 5/4	sand	2.8	7.1	49	0.4
3	A	2	10YR 3/1	sand	13.2	6.9	116	4.7
	C	36	10YR 4/3	sand	3.7	7.1	59	0.5
6	A	3	10YR 4/2	sand	5.2	7.1	62	1.7
	C	18	10YR 5/3	sand	3.8	6.8	35	0.4
7	A	2	10YR 3/1	sand	10.1	6.5	80	3.5
	C	105	10YR 4/2.5	sand	4.6	6.5	42	0.6
4	A	1	10YR 4/3	sand	5.2	7.1	81	1.1
	C	3	10YR 5/3	sand	5.0	7.3	80	0.8
5	A	5	10YR 4/1	sand	8.4	6.8	65	1.8
8	A	3	10YR 3/1	sand	17.1	7.2	146	6.9
	C	90	10YR 6/2	sand	12.3	8.0	109	0.6

[a] See Table 1 for release information.
[b] According to Munsell (1975).

seeding, or herbicide drift. At three sites the number of beetles released was not recorded. In the remainder it varied from 60 to 500 (Table 1).

Plant Species Composition

We recorded 54 vascular plant taxa, plus mosses and lichens, representing 24 families (Appendix). Five of the taxa were annuals, namely *Panicum capillare* (witchgrass), *Androsace* sp. (pygmy flower), *Chenopodium leptophyllum* (lamb's quarters), *Erigeron canadensis* (horseweed), and *Silene capillare* (sleepy catchfly). The perennials included four introduced species: *Euphorbia esula* (leafy spurge), *Bromus inermis* (smooth bromegrass), *Poa pratensis* (Kentucky bluegrass), and *Medicago sativa* (alfalfa). Kentucky bluegrass, leafy spurge, and sedges were the only species present in all sites. Sedges (*Carex siccata, C. obtusata,* and *C. stenophylla*) were the most abundant graminoids, and they had high frequencies of occurrence in all sites, as did leafy spurge (Appendix). *Bouteloua gracilis* (blue grama grass), smooth brome, Kentucky bluegrass, *Equisetum hyemale* (scouring rush), *Selaginella densa* (spikemoss), and lichens and mosses all had frequencies that exceeded 15% in one or more sites.

Sixteen taxa occurred only at sampling points where beetles had been released (Appendix). Nine native taxa had frequencies greater than 8% at sampling points where beetles had been released for six years, compared with two species where beetles had been released only two years earlier. Six native species occurred only at the points where beetles had been released for six years; these were *Koeleria cristata* (June grass), *Agropyron smithii* (western wheatgrass), *Zigadenus elegans* (white camas), sleepy catchfly, *Artemisia campestris* (common sagewort), and *Rhus radicans* (poison ivy). The average number of plant species at the release point was always higher than at the nearby nonrelease reference point: 30 species vs. 23 where beetles had been released for six years; 29 vs. 22 where beetles had been released for four years; and 11 vs. 9 where beetles had been released for two years.

The number of plant species at the reference points sampled ranged from 9 to 23. Leafy spurge dominated the nonrelease reference points: the 1986 sites had 59% cover, the 1988 sites had 42% cover, and the 1990 sites had 50% cover (Fig. 1). In comparison, the average cover of leafy spurge at beetle release points was: 6% at the 1986 release sites, 11% at the 1988 sites, and 25% at the 1990 sites. At all of the nonrelease reference points the mean height of spurge was 60 cm, whereas it ranged from 24 cm (1988) to 33 cm (1990) at the points where beetles had been released (Fig. 1).

Leafy Spurge Suppression

All nine sites at the points where beetles had been released showed an obvious area of lower spurge growth and density. We focused our release site data collection within that area. When comparing release and adjacent nonrelease reference sites, close to where the beetles had been released, there was significantly lower spurge cover (Wilcoxon $T = -2.55$, $p \leq 0.01$), biomass ($T = -2.31$, $p \leq 0.02$), height ($T = -2.67$, $p \leq 0.01$), and stem density ($T = 2.65$. $p \leq 0.01$). Only the frequency of spurge stems did not vary significantly (T = -1.83, $p \leq 0.07$). Spurge was consistently found in the quadrats, despite its lower height, cover, and density.

Associated with reduced spurge dominance of the local plant community, the quantity of spurge and litter also was lower. Both litter frequency and cover were lower near the release point than at the paired nonrelease reference point (T = 1.83, $p \leq 0.07$, and T = 1.60, $p \leq 0.11$, respectively). This resulted in significantly higher frequency of bare ground frequency (T = 2.52, p = 0.01), and possibly lower cover (T = 1.72, $p \leq 0.09$), at the release point.

Interestingly, the total number of plant species did not increase significantly with the increase in bare ground (species richness, T = 1.05, p = 0.30), although the number of species per quadrat appeared higher (T = 1.78, p = 0.08). However, the biomass of grasses was significantly greater (T = 2.31, p = 0.02). These findings suggest that species already present at the site, especially vegetatively reproducing species such as native perennial grasses (e.g, blue grama grass, *Andropogon scoparius* (= *Schizachrium scoparium* [Michx.] Nash) (little bluestem), and *Calamovilfa longifolia* (sand grass), spread into the bare ground.

Although no significant differences in leafy spurge frequency were detected between release years, there was a major decrease in spurge cover (Fig. 1A) and biomass (Fig. 1B) at the release points compared with the nearby nonrelease reference points. Six years after beetle release, mean leafy spurge cover around the release points was 98% lower than in the nearby nonrelease reference points. After only two years of beetle activity, spurge cover was 20% lower than at the nearby reference point, and after four years of beetle activity, cover was approximately 38% lower. At the beetle release points, two years after beetle release, leafy spurge relative biomass was 84% compared with 43% at the nonrelease reference points. For each release year, the reduction in mean height near the release point (Fig. 1C) and spurge density (Fig. 1D) was maintained over time. The largest difference in height occurred six years after beetle release (Fig. 1C). After six years, relative biomass of leafy spurge at the release points was 17% compared with 44% at the nonrelease reference points (Fig. 1F).

Discussion

Ideally, an approach to investigating the impact of a biological control agent on a target species would be to sample a number of locations, preferably with randomly allocated replicate samples, both before and after the release of the control agent. Each release point and an adjacent nonrelease reference point at the site would be resampled over a long period of time (Green 1979). In this study, we did the next best thing, since the black dot flea beetles (*Aphthona nigriscutis*) had already been released by Manitoba Agriculture two or more years before the study began (Mico 1993). Our study examined sites where beetles had been released six, four, and two years before we sampled, and we compared plant performance at release points with that at randomly chosen nearby nonrelease reference points. The release and reference points had similar soil and other characteristics. We sampled late in the season when a number of plant species that would have been evident in the spring or early summer had died back. More ephemeral species might have been present in the quadrats had we sampled earlier in the growing season.

The data suggest that the beetles have had significant impacts on leafy spurge, as well as on the diversity of native species, near the release points. Although leafy spurge occurred in all our quadrats at about the same frequencies, its cover, biomass, and height were significantly lower close to (<5 m) where beetles had been released. Evidence of greater negative impact by the beetles on leafy spurge was correlated with time since release. Leafy spurge cover was lowest at points where the beetles had been released six years before (6% vs. 59% at nonrelease reference points), but the differences were progressively less for sites four years old (11% vs. 42%) and two years old (25% vs. 50%). Currently, 10% cover of leafy spurge is defined as "control," since this amount of leafy spurge displaces little native or forage plant species (P. Harris personal communication). Thus, it seems that after about four years, leafy spurge can be reduced to the "control" level near the beetle release points.

Our results are consistent with those of other monitoring studies and observations. Flea beetles appear to have reduced spurge infestations over large areas in several western provinces and states (Hansen 2000). They have been considered effective elsewhere in Manitoba where spurge density has decreased by 95% at some of the earliest release sites. (Manitoba Agriculture 1997). Also, where beetles have become well established in Saskatchewan, there has been a reduction in the biomass of spurge and an increase in biomass of grasses and other herbaceous species (Saskatchewan Agriculture and Food 2000). Other studies also have suggested the efficacy of biological control agents in reducing the cover and density of leafy spurge, for example, in east-central North Dakota (Kirby et al. 2000). In addition, among 85 biological control sites across Minnesota that were monitored in 2000, leafy spurge was judged as being controlled in 41% of 566 ha (1400 acres) (Cortilet 2000).

Along with the local decline in leafy spurge cover, we found a concomitant increase in the diversity of native species per quadrat. Beetle release points had significantly greater species diversity, grass biomass, and bare ground than did nearby nonrelease points. Several native grasses and forbs occurred only at sites where beetles had been active for six years. We conclude that there is a slow, gradual return of the native flora as leafy spurge is suppressed.

In spite of the promising results of this and other studies of leafy spurge suppression through biological control, we need to learn much more about the biology and spread of the host species leafy spurge, its insect predators, and how well it can be integrated with other suppression strategies such as herbicides and grazing. No one tool appears adequate to deal with the current massive infestation, but biologically based, integrated pest management may be our best hope.

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APPENDIX
PERCENT FREQUENCY OF TAXA IN MIXED-GRASS PRAIRIE INFESTED WITH LEAFY SPURGE. BLACK DOT BEETLES WERE RELEASED IN DIFFERENT SITES IN 1986, 1988, AND 1990

			Year of Beetle Release					
	Life		1986		1988		1990	
Common name (Scientific name)[a]	history[b]	Origin[c]	R[d]	NR[e]	R	NR	R	NR
Grasses and Sedges								
Western wheatgrass (*Agropyron smithii* Rydb.)	P	N	3.3	-	-	-	-	-
Big bluestem (*Andropogon gerardi* Vitman)	P	N	-	18.3	1.7	6.7	-	-
Little bluestem (*A. scoparius* Mich.)	P	N	18.3	-	3.3	1.7	-	-
Tall grama (*Bouteloua curtipendula* [Michx.] Torr.)	P	N	1.7	-	-	1.7	-	-
Blue grama (*B. gracilis* [HBK.] Lag.)	P	N	46.7	-	38.3	26.7	-	-
Smooth brome (*Bromus inermis* Leyss.)	P	I	-	25	-	-	76.7	23.3
Sand grass (*Calamovilfa longifolia* [Hook.] Scribn.)	P	N	12	-	21.7	13.3	1.7	8.3
Sedge (*Carex* L. spp.): *C. obtusata, C. siccata, and C. stenophylla.*	P	N	100	68.3	96.7	85	96.7	76.7
Fescue (*Festuca ovina L. var. saximontana* [Rydb.] Gl.)	P	N	1.7	-	-	1.7	-	-
June grass (*Koeleria cristata* [L.] Pers.)	P	N	7	-	-	-	-	-
Witchgrass (*Panicum capillare* L.)	A	N	1.7	-	-	1.7	-	-
Kentucky blue grass (*Poa pratensis* L.)	P	I	16.7	13.3	40	40	43.3	31.7
Needle-and-thread (*Stipa comata* Trin. & Rupr.)	P	N	-	1.7	1.7	-	-	-
Forbs								
Nodding onion (*Allium cernuum* Roth.)	P	N	5	-	1.7	-	-	-
Pygmy flower (*Androsace* L. spp.)	A	N	13.3	5	6.7	5	-	1.7
Long-fruited anemone (*Anemone cylindrica* Gray)	P	N	1.7	1.7	-	-	-	-
Common sagewort (*Artemisia campestris* L.)	P	N	1.7	-	-	-	-	-
Fringed sagebush (*A. frigida* Willd.)	P	N	-	-	-	1.7	-	-
Bellflower (*Campanula rotundifolia* L.)	P	N	-	3.3	-	-	-	-
Lambs quarters (*Chenopodium leptophyllum* [Moq.] Nutt. ex S. Wats.)	A	N	6.7	-	21.7	-	-	-
Golden aster (*Chrysopsis villosa* [Pursh] Nutt.)	P	N	-	-	-	3.3	-	-
Bastard toadflax (*Comandra umbellata* [L.] Nutt.)	P	N	23.3	-	10	-	-	-
Scouring rush (*Equisetum hyemale* L.)	P	N	28.3	28.3	18.3	6.7	1.7	-
Fleabane (*Erigeron glabellus* Nutt.)	P	N	5	5	-	-	-	-
Horseweed (*E. canadensis* L.)	A	N	-	-	1.7	-	-	-
Western wallflower (*Erysimum asperum* [Nutt.] DC.)	P	N	1.7	-	1.7	1.7	-	-
Small flowered wallflower (*E. inconspicuum* [Wats] Mac. M.)	P	N	-	-	11.7	-	-	-

APPENDIX continued

Leafy spurge (*Euphorbia esula* L.)	P	I	91.6	100	95	100	81.7	100
Northern bedstraw (*Galium boreale* Pursh.)	P	N	8.3	6.7	1.3	-	-	-
Three flowered avens (*Geum triflorum*Pursh.)	P	N	-	-	1.3	-	-	-
Rhombic-leaved sunflower (*Helianthus laetiflorus* Pers. var. *subrhomboideus* [Rydb.] Fern.)	P	N	5	5	-	-	-	-
Sunflower (*Helianthus* L. spp.)	P	N	-	-	1.3	-	-	-
Alumroot (*Heuchera richardsonii* R. Br.)	P	N						
Cream colored vetchling (*Lathyrus ochroleucus* Hook.)	P	N	-	-	-	-	8.3	21.7
Hoary puccoon (*Lithospermum canescens* [Michx.] Lehm.)	P	N	-	8.3	-	1.7	-	-
Skeleton weed (*Lygodesmia junceae* [Pursh]. D.Don)	P	N	-	-	1.7	-	-	-
Alfalfa (*Medicago sativa* L.)	P	I	-	-	-	-	1.7	-
Ground-cherry (*Physalis virginiana* Mill.)	P	N	1.7	-	-	-	1.7	-
Spikemoss (*Selaginella densa* Rydb.)	P	N	48.3	-	18.3	20	-	-
Sleepy catchfly (*Silene antirrhina* L.)	A	N	1.7	-	-	-	-	-
False Solomon's seal (*Smilacina stellata* [L.] Desf.)	P	N	-	1.3	3.3	-	1.7	-
Veiny meadow rue (*Thalictrum venulosum* Trel.)	P	N	-	1.3	-	-	-	-
Violet (*Viola* L. spp.)	P	N	-	3.3	-	-	-	-
White camass (*Zigadenus elegans* Pursh.)	P	N	5	-	-	-	-	-
Shrubs								
Saskatoon berry (*Amelanchier alnifolia* Nutt.)	P	N	-	6.7	3.3	-	-	-
Creeping juniper (*Juniperus horizontalis* Moench)	P	N	23.3	10	-	5	-	-
Common chokecherry (*Prunus virginiana* L.)	P	N	-	-	1.7	-	-	-
Poison ivy (*Rhus radicans* L.)	P	N	5	-	-	-	-	-
Rose (*Rosa* L. spp.)	P	N	10	20	5	13.3	-	-
Carrion flower (*Smilax herbacea* L.)	P	N	-	-	1.6	-	-	-
Meadow sweet (*Spiraea alba* DuRoi)	P	N	-	1.7	3.3	10	-	-
Western snowberry (*Symphoricarpos occidentalis* Hook.)	P	N	-	1.7	-	-	-	-
Lichens			70	-	26.6	18.3	-	1.7
Musci			-	26.7	16.6	11.7	1.7	1.7

Notes: Sampling data were collected in August 1992 and represent the mean of three sites (N = 60) for each release date.

[a] Common names follow Alex et al. (1980) and scientific names follow Scoggan (1978-79) except for *Schizachrium scoparium* (Michx.) Nash.

[b] P = Perennial, A = Annual

[c] N = Native, I = Introduced

[d] R = Point where beetles were released ($\leq$ 5m from stake).

[e] NR = Randomly chosen nearby nonrelease reference point ($\geq$10 m from release point), as a control.

\- Dashes indicate species or taxon not present.